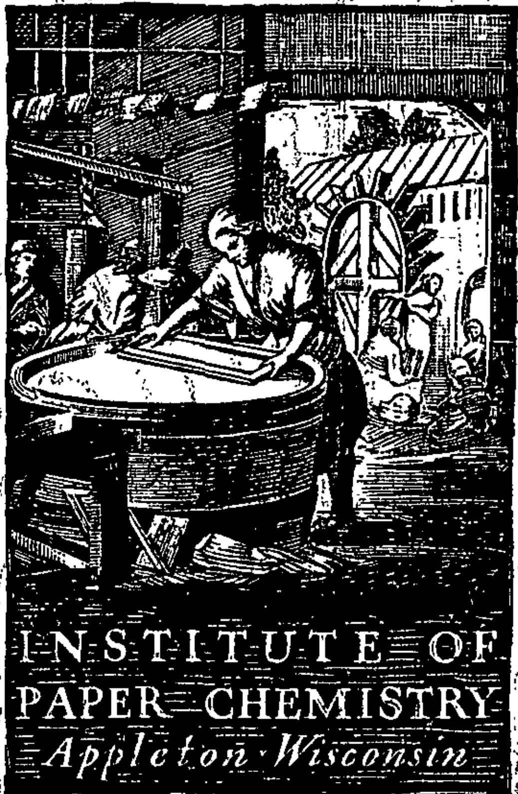


THE RELATIONSHIP OF THE G. E. PUNCTURE TEST AND OTHER CONVENTIONAL TESTS TO TYPE AND DEGREE OF BEATING, BASIS WEIGHT, DENSITY, AND NONFIBROUS ADDITIVES

Project 1108

Progress Report Eight

to the

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

April 1, 1956

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

THE RELATIONSHIP OF THE G. E. PUNCTURE TEST AND OTHER CONVENTIONAL TESTS TO TYPE AND DEGREE OF BEATING, BASIS WEIGHT, DENSITY, AND NONFIBROUS ADDITIVES

Project 1108

Progress Report Eight

to the

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

April 1, 1956

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

SUMMARY

This study was undertaken for the purpose of investigating the relationship of the G. E. puncture test and other conventional tests to type and degree of beating, basis weight, density, and nonfibrous additives. Handsheets were made at various intervals of beating from stock processed in three different beaters--namely, the Valley beater, pebble mill, and Jokro mill in order to study the effect of the type and degree of beating. The effect of basis weight on the G. E. puncture test was investigated by making handsheets at weights varying from a minimum of 42 lb. to a maximum of 150 lb. (25 x 40/500) from pulp beaten to the same freeness level. The effect of density variation was studied by making sheets at a basis weight level of 42 lb. (25 x 40/500) and wet pressing one-third of the sheets at 25 p.s.i., one-third at 50 p.s.i., and one-third at 100 p.s.i. The effect of adding nonfibrous additives to the same furnish was studied by adding Hyamine, and Lycoid.

The handsheets prepared for each phase of this investigation were tested for basis weight, caliper, bursting strength, G. E. puncture, Baldwin-Southwark tensile and stretch, ring compression, and Elmendorf tear.

The results are summarized below.

EFFECT OF TYPE AND DEGREE OF BEATINGS ON G. E. PUNCTURE

In order to explore the relationship between beating and the G. E. Puncture strength of handsheets, three different types of beating tackle were employed--namely, Valley beater, Abbé pebble mill, and Jokro mill. It was concluded that, of the physical tests made, only Elmendorf tear behavior shows a marked similarity to the behavior of G. E. puncture when the test results are plotted against intervals of beating time. This was apparent for all three types of beating tackle. Both G. E. puncture and Elmendorf tear reach a maximum level early in the beating cycle and then decrease gradually as beating continues whereas the other tests--bursting strength, ring compression, tensile strength, stretch, and apparent density--increase gradually throughout the entire beating period.

EFFECT OF WEIGHT ON G. E. PUNCTURE

To study the effect of weight on the G. E. Puncture test, handsheets of various weights were made from pulp beaten in a Valley beater to a constant freeness level. In one series of tests, handsheets were prepared from pulp which had been beaten to a Canadian standard freeness level of 600 cc.; in another series of tests, handsheets were prepared from pulp which had been beaten to a Canadian standard freeness level of 400 cc. The basis weights studied on a scale of 25 x 40/500 were 42, 67, 92, 125, and 150 lb. The test results show that all tests increased as weight increased. On the basis of units of strength per pound of basis weight, Elmendorf tear and G. E. puncture exhibited more strength units per pound of fiber as weight increased, whereas bursting strength exhibited more strength units per pound of basis weight in the low range of weight and decreasing strength units per pound of basis weight in the intermediate and high ranges of weight.

EFFECT OF DENSITY ON THE G. E. PUNCTURE TEST

Handsheets were made at a basis weight level of 42 lb. (25 x 40/500). To vary the density, these sheets were wet-pressed at pressures of 25, 50, and 100 p.s.i. Apparent density was not affected very greatly by this range of pressures, the values ranging from 9.1 to 9.6 lb. per point. The bursting strength factor was 0.980 at 25 p.s.i. and 1.081 at 100 p.s.i., indicating that wet pressing at 100 p.s.i. increased bursting strength. The G. E. puncture factors were not changed appreciably, and the tensile factor and percentage stretch were only slightly affected. The tear factor decreased from 1.73 at 25 p.s.i. to 1.62 at 100 p.s.i.

EFFECT OF NONFIBROUS ADDITIVES ON THE G. E. PUNCTURE TEST

Sheets were prepared from a uniform batch of pulp; to one portion, Hyamine was added in amounts of 0.5 and 5.0%; to another portion, Lycoid was added in amounts of 0.25 and 1.0%. Physical tests were performed on each set of sheets. By its nature, Hyamine is surface-active and hence tends to decrease fiber bonding. Its effect was to reduce bursting strength, tensile strength, stretch and ring compression and to have little effect on G. E. puncture and Elmendorf tear. The action of Lycoid, on the other hand, is to increase fiber bonding. The effect noted was to increase bursting strength, affect only slightly tensile and stretch, and decrease ring compression slightly. The effect of Lycoid on the G. E. puncture test results was imperceptible; the Elmendorf tear results were reduced somewhat.

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

THE RELATIONSHIP OF THE G. E. PUNCTURE TEST AND OTHER CONVENTIONAL TESTS TO TYPE AND DEGREE OF BEATING, BASIS WEIGHT, DENSITY, AND NONFIBROUS ADDITIVES

INTRODUCTION

Since the introduction of the G. E. puncture test as a device for evaluating the quality of corrugated and solid fiber combined board, a number of studies have been carried out to determine the relationship of the G. E. puncture test to various properties of corrugated board. With few exceptions, the results have shown that the G. E. puncture test results on corrugated combined board correlate better with box performance--i.e., box compression--than any other single combined board test. Although the G. E. puncture test has certain drawbacks as a criterion of combined board quality, the evidence to date indicates that it is a better means of evaluation than the bursting strength test which is the only strength test currently specified in Rule 41. If the G. E. puncture test were to replace the bursting strength test, one of the first questions which undoubtedly would arise would be what test should be used in controlling the quality of the components. Like bursting strength, the G. E. puncture test is not fundamental but rather measures a complex group of properties such as initial and continued tearing strength, tensile strength, stretch, resistance to bending, et cetera. Hence, one would expect its relationship to beating also to be complex and somewhat unpredictable. This study was undertaken, therefore, to develop information relative to one part of this general question, namely, what is the relationship between degrees of beating and the G. E. puncture of liners and corrugating medium. The relationship between beating and conventional paper properties such as density, bursting strength, tensile, stretch, stiffness, and Elmendorf tear have been well established. However, no such relationship could be found in the literature for the G. E. puncture test. In order to determine whether the type of beating--i.e., cutting vs. "hydration"--had a marked influence on this relationship, a standard pulp (unbleached kraft) was refined by three different types of tackle--namely, Valley beater, pebble mill, and a Jokro mill. The latter equipment has been rather widely used on the European continent for evaluating pulps.

In order to determine the effect of the type and degree of beating on the G. E. puncture test, "beater runs" were made with each type of "beater"; test handsheets were made at different intervals of beating corresponding to different freenesses. The test sheets at each interval of beating were evaluated for basis weight, caliper, bursting strength, G. E. puncture, tensile strength, percentage stretch, ring compression, and Elmendorf tearing strength. In addition, the freeness and beating time were recorded for each interval.

The effect of basis weight on the G. E. puncture test was investigated by making handsheets at weights varying from a minimum of 42 lb. to a maximum of 150 lb. (25 x 40--500) from pulp which had been beaten to a uniform freeness level.

To study the effect of density, handsheets were made at a basis weight of 42 lb. (25 x 40--500) and the density was varied by wet pressing one-third of these sheets at a pressure of 25 p.s.i., one-third at a pressure of 50 p.s.i., and one-third at a pressure of 100 p.s.i.

In order to investigate the effect on the G. E. puncture test of adding nonfibrous additives to the furnish, handsheets were prepared from pulp to which various percentages of three nonfibrous materials had been added--namely, Hyamine, Lycoid, and starch. Hyamine is a surface-active agent and hence tends to reduce fiber bonding whereas Lycoid and starch tend to increase fiber bonding.

The detailed procedures followed in each phase of this study are described in detail below.

GENERAL PROCEDURES IN HANDSHEET PREPARATION

The factors to be investigated included the following: type and degree of beating, basis weight, density, and addition of nonfibrous additives. The procedures followed in studying each of these factors will be described individually in the order given above.

EFFECT OF TYPE AND DEGREE OF BEATING

In order to explore the relationship between beating and the G. E. puncture strength of handsheets, three different types of beating tackle were employed. The three were selected to represent conditions of maximum cutting and minimum "hydration" to maximum "hydration" and minimum cutting. The "beaters" used in this study were the 1-1/2 pound Valley beater, Abbé pebble mill, and the Jokro mill. The latter is used very extensively on the European continent for evaluating pulp. Maximum cutting and minimum hydration are associated with the Valley beater; maximum hydration and minimum cutting, on the other hand, are associated with the Abbé pebble mill; and the Jokro mill represents a position somewhere between these two extremes.

A. Beater Evaluation

One lot of pulp was used throughout this study. The particular pulp was an unbleached kraft pulp made in Finland. The "beater" runs using this pulp were made as follows:

1. Valley Beater

For this purpose a 1-1/2 pound Valley beater was used. Institute Method 403 was followed, using a 6500-g. weight on the bedplate. In order to obtain the required quantity of stock, five beater runs were made. The sampling intervals used were 0, 5, 10, 20, 35, 50, and 65. The stock from the five runs at corresponding beating times were combined to form one composite for that interval. Samples for freeness and fiber classification tests were withdrawn from this composite for each interval. At each beating interval, fifteen handsheets, weighing approximately 2.23 grams ovendry, were made on an 8 by 8-inch Noble and Wood mold, using an 80-mesh wire. The couched sheets were pressed between blotters at 50 p.s.i.--half a minute to and five minutes at this pressure--and then dried on a steam-heated drier.

2. Jokro Mill

The Jokro mill consists (see Figure 1) of a milling chamber which rotates on a horizontal plane around a central axis at the rate of 150 r.p.m. It also rotates around its own axis at 1.14 x 150 r.p.m. The

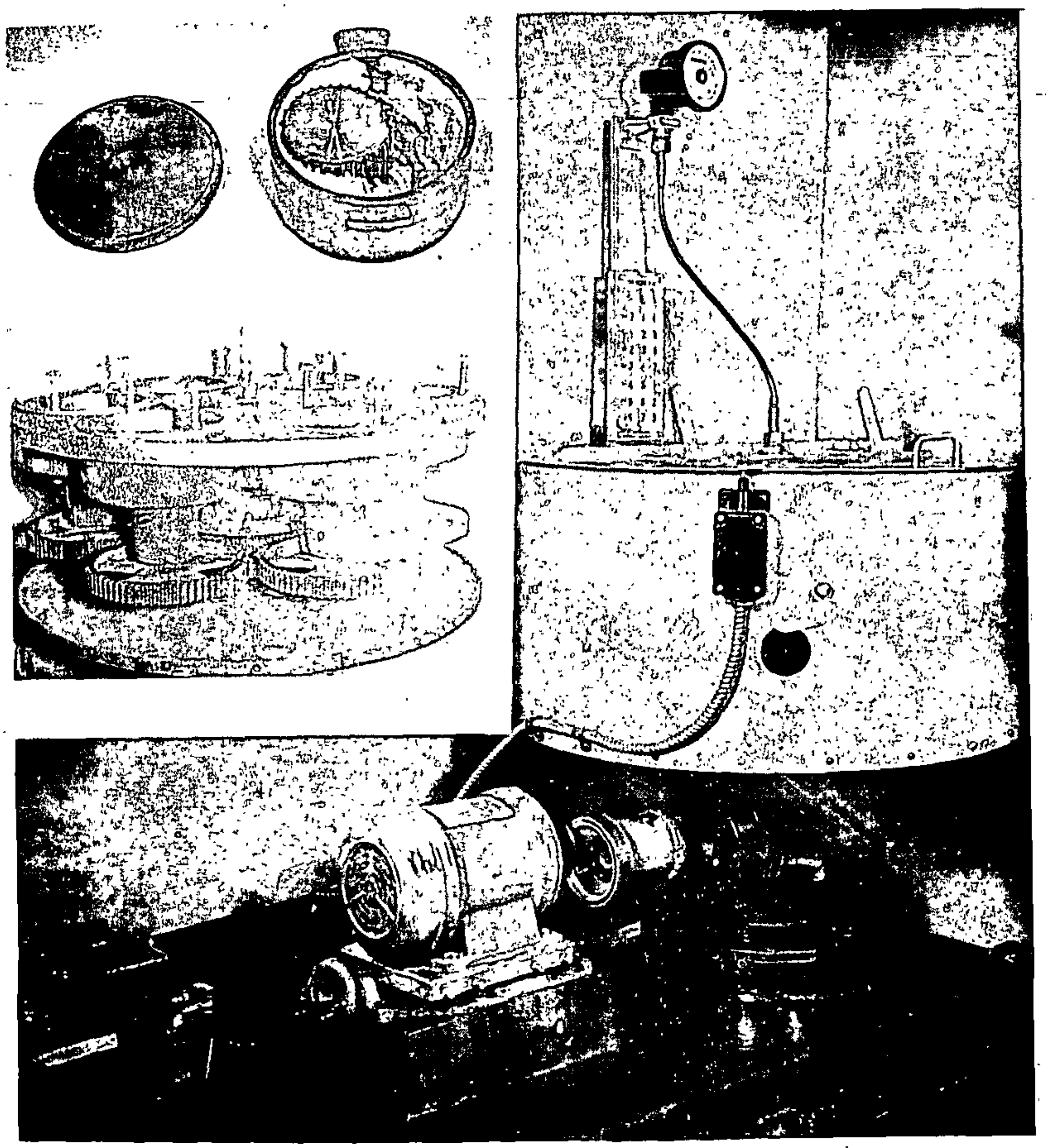


Figure 1. Jokro Mill

beating roll is put into the milling chamber in such a manner that it is brought into contact with the inner surface of the chamber by reason of the centrifugal force generated by the rotation. The action of the chamber causes the roll to spin around the periphery of the container, thus creating a refining area at the juncture of the two parts. The pulp charge which is 16 grams ovendry at 6% consistency, forms a pad around the chamber wall which reacts to the impact of the beater roll.

Prior to charging the Jokro mill, the pulp was soaked for four hours in water at room temperature and defibered in the British disintegrator for 600 counts (15,000 revolutions) at a consistency of approximately 4%. The pulp was then dewatered, the cake broken and a moisture determination made to determine the weight of wet pulp equivalent to 16 g. ovendry. In order to provide the necessary quantity of stock at each beating interval, four runs were made in the Jokro mill. The beating intervals used were 10, 20, 30, 45, 60, and 80 minutes. As in the case of the Valley beater runs, the stocks at like beating intervals were combined, diluted to 2000 cc., cleared in the British disintegrator for 50 counts on the counter. The stock was then diluted to 6400 ml. Three hundred milliliters were withdrawn for a freeness determination and two 1000-ml. samples withdrawn for fiber classification determination. The balance of the stock was diluted to approximately 15 liters and fifteen handsheets made as described in A-1 above for the Valley beater.

3. Pebble Mill Evaluation

The pebble mill evaluation was carried out in accordance with Institute Method 404 using flint pebbles. Six runs were made corresponding to 20, 40, 60, 100, 160, and 270 minutes; in addition, a sample was collected at 0 time. Upon completion of the desired beating time, the 90-g. charge was diluted to approximately 4 liters and cleared in the British disintegrator (300 counts) in two batches. The stock was then diluted to approximately 1% consistency and the consistency determined. The calculated quantity of stock was measured out for freeness and fiber classification determinations. The balance of the stock was diluted to approximately 15 liters and fifteen handsheets per beating interval were made as described in A-1 above for the Valley beater.

As previously mentioned, freeness and fiber classification determinations were made at each interval of beating. Canadian Standard freeness determinations were run in accordance with Institute Method 417. Fiber classification determinations were made as directed in Institute Method 415 with the Bauer-McNett classifier using 20, 35, 65, and 100-mesh screens.

EFFECT OF WEIGHT ON G. E. PUNCTURE

The effect of weight on the G. E. puncture test was studied in two phases. Phase one involved refining the pulp to a Canadian Standard freeness level of 600 cc. and phase two involved refining the pulp to a Canadian standard freeness level of 400 cc. The procedures followed in carrying out this study are described below.

Phase one involved beating two separate charges of Finnish kraft pulp in the No. 2 Valley beater for 35 minutes. The Canadian Standard freeness for the first run was 580 cc. and for the second run 600 cc. The two charges were mixed and used to make sheets of the following weights on the basis of lb. (25 x 40/500): 42, 67, 92, 125, and 150.

Phase two involved beating two separate charges of Finnish kraft pulp in the No. 2 Valley beater for 60 minutes. The Canadian standard freenesses for the two changes were 395 and 410 cc. The two charges were mixed and used to make sheets of the same weights as were made at the higher freeness.

All sheets were pressed at 50 p.s.i. in a Williams' press and dried on a steam-heated drum drier.

EFFECT OF DENSITY ON G. E. PUNCTURE

The procedures followed in studying the effect of density on the G. E. puncture test are described below.

Two charges of Finnish unbleached kraft were beaten in the No. 2 Valley beater for 35 minutes each with a bedplate load of 6500 grams. Canadian standard freenesses for the two charges were 580 and 600 cc. The two charges were combined, and sheets were made at a basis weight of 42 lb. (25 x 40/500). To vary the density, one-third of the sheets were wet-pressed at 25 p.s.i., one—third at 50 p.s.i., and one-third at 100 p.s.i.

EFFECT OF ADDING NONFIBROUS MATERIALS TO FURNISH

In order to study the effect on the G. E. puncture test of adding nonfibrous materials to the furnish, handsheets were prepared from pulp to which various percentages of three nonfibrous materials had been added---namely, Hyamine, Lycoid, and starch. The Hyamine was added to reduce fiber bonding while the Lycoid was added to increase fiber bonding. The procedures followed in the preparation of these combinations are reported below.

PREPARATION OF BASELINE PULP

Pulp for use in making handsheets with the various additives was prepared as follows:

Two charges of Finnish unbleached kraft pulp were beaten 35 minutes with a bedplate load of 6500 grams in the No. 2 Valley beater. The Canadian standard freenesses of the two charges were 595 cc. and 585 cc. The two charges were combined and used in the preparation of 8 by 8-in. sheets.

PREPARATION OF HANDSHEETS FROM HYAMINE-TREATED PULP

0.5% HYAMINE

Sixty grams of ovendry baseline pulp at a consistency of 1.57% were placed in a Pyrex glass battery jar and stirred with a Model V Lightnin' mixer equipped with two propellers on the shaft. One-half per cent Hyamine 2389 based on the ovendry weight of pulp was added to the pulp, and the slurry was stirred 15 minutes at a speed sufficient to maintain circulation. Because the Hyamine was in the form of a solution containing 50% water, 0.6 cc. of solution was required assuming that the density of the Hyamine solution was 1.0. After the Hyamine treatment, the stock was diluted to 0.25% consistency in a stainless steel kettle and fifteen 8 by 8-in. 2.23-gram (ovendry basis) sheets were formed on an 80-mesh wire in the Valley sheet mold. The sheets were pressed 5 minutes at 50 p.s.i. in the Valley press and dried 10 to 12 minutes on the stationary drum drier (steam pressure = approximately 15 p.s.i.)

5.0% HYAMINE

Sheets were formed from pulp which had been treated with 5.0% Hyamine based on the ovendry weight of pulp. The treatment and sheet preparation procedure were the same as employed for the pulp treated with 0.5% Hyamine.

PREPARATION OF HANDSHEETS FROM LYCOID-TREATED PULP

PREPARATION OF LYCOID

Six hundred milliliters of water and 4 g. of Lycoid were placed in a one-liter Erlenmeyer flask, stirred with a small glass-rod mixer, heated to about 90-95°C. for 10-15 minutes on a steam bath, and diluted to 800 grams.

PREPARATION OF SHEETS

Sheets were prepared in the same manner as the Hyamine-treated sheets from 50 grams of ovendry stock which had been treated with 0.25% Lycoid based on the ovendry weight of pulp and from 50 grams of ovendry stock which had been treated with 1.0% Lycoid based on the ovendry weight of pulp. The Lycoid supplier was Stein-Hall and Co. A quantity of 1 N hydrochloric acid sufficient to produce a slurry pH of about 5 in the sheet mold (approximately 2.5 cc. were required) was added to the water in the mold prior to the addition of the stock. The method of treatment was essentially the same as that employed for the Hyamine treatment with the exception that the 0.25% consistency pulp slurry was adjusted to a pH of 5.4 with 1 N hydrochloric acid.

PREPARATION OF ROSIN SIZE

Twenty-nine and nine-tenths grams of Hercules rosin size "T" (41.84% solids) was diluted to 250 cc. with hot water (concentration 5 grams size/100 cc. solution).

GENERAL PROCEDURES IN PHYSICAL TESTING OF HANDSHEETS

Prior to being tested, all samples were preconditioned for 24 hours in an atmosphere maintained at 35% relative humidity and 73°F. Following the prescribed preconditioning, the samples were conditioned for at least 48 hours in an atmosphere maintained at 50 ± 2% relative humidity and 73 ± 3.5°F. temperature and then tested in the same atmosphere. The tests and procedure used were as follows:

1. Caliper

Two determinations were made on each of fifteen handsheets as directed in Institute Method 508.

2. Basis Weight

Institute Method 504 was followed. The fifteen handsheets per sample were trimmed to 7.75 by 7.75 inches and weighed. The basis weight was computed on a 25 x 40--500 ream size.

3. Bursting Strength

Using a motor-driven Model C tester, the test was performed in accordance with Institute Method 510. One determination was made on each of the fifteen sheets per sample.

4. G. E. Puncture

One determination was made on each of fifteen sheets per sample in accordance with procedure outlined in Institute Method 917.

5. Elmendorf Tear

Institute Method 512 was followed. Two sheets were tested simultaneously.

6. Tensile and Stretch

The tensile and stretch determination was made using a Baldwin-Southwark Universal testing machine. Institute Method 511 was followed. A one-inch specimen and a span of six inches was used. One determination was made on each of fifteen handsheets per sample.

7. Ring Compression

Institute Method 915 was used. One determination was made on each of fifteen sheets per sample.

DISCUSSION OF RESULTS

As pointed out earlier in this report, the objective of this study was to determine or elucidate the relationship of the G. E. puncture test on components to other tests that are conventionally used to characterize their strength properties--e.g., bursting strength, basis weight, caliper, apparent density, tensile strength, stretch, ring compression, and tearing strength. Certain variables which may influence any one of these tests were investigated--e.g., the type and degree of beating, basis weight, density, and addition of nonfibrous additives. Each of the aforementioned factors will be discussed separately in the ensuing commentary.

EFFECT ON SHEET PROPERTIES OF THE TYPE AND DEGREE OF BEATING

In order to study the effect of the type and degree of beating, three types of beater evaluations were made---namely, (1) Valley beater, (2) Abbé pebble mill, and (3) the Jokro mill. The test results for the Valley beater evaluation are shown in Table I. Graphic presentations of physical properties _versus_ beating time for the beater evaluations by the Valley beater method are shown in Figure 2. The physical properties presented graphically in Figure 2 are apparent density, bursting strength,

TABLE I

THE EFFECT OF THE TYPE AND DEGREE OF BEATING ON SHEET PROPERTIES

Valley Beater

Beating Time, min.	Freeness, cc. (Canadian Standard)	Basis Weight, lb. 25x40/500	Caliper points	Apparent Density	Bursting Strength, p.s.i.	Bursting Strength, Factor[a]	G. E. Puncture, units	G. E. Puncture, Factor[a]	Tensile Strength, lb./in.	Tensile Strength, Factor[a]	Stretch, %	Ring Compression, lb.	Ring Compression, Factor[a]	Elmendorf Tear, g./sheet	Elmendorf Tear, Factor[a]
0	745	39.8	6.1	6.5	3.8	0.095	1	0.025	3.0	0.075	0.8	2.1	0.053	34	0.85
5	715	40.3	5.7	7.1	11.1	0.275	4	0.099	6.6	0.164	1.5	4.4	0.109	69	1.71
10	695	39.7	5.2	7.6	19.5	0.491	5	0.126	10.3	0.259	2.0	5.9	0.149	89	2.24
20	675	39.3	4.5	8.7	31.8	0.809	6	0.153	16.2	0.412	2.6	7.6	0.193	75	1.91
35	605	39.7	4.1	9.7	46.4	1.169	6	0.151	22.3	0.562	3.1	8.2	0.207	65	1.64
50	475	39.4	3.9	10.1	51.5	1.307	6	0.152	25.3	0.642	3.3	8.7	0.221	63	1.60
65	320	39.2	3.6	10.9	56.6	1.444	5	0.128	28.3	0.722	3.6	8.1	0.207	52	1.33

Beating conditions: Type of refiner, 1-1/2-lb. Valley beater; Furnish, unbleached kraft; consistency, 1.57%; Weight on bedplate, 6500 g.; Temperature: 73°F.

[a] Factors were calculated by dividing test result by the basis weight.

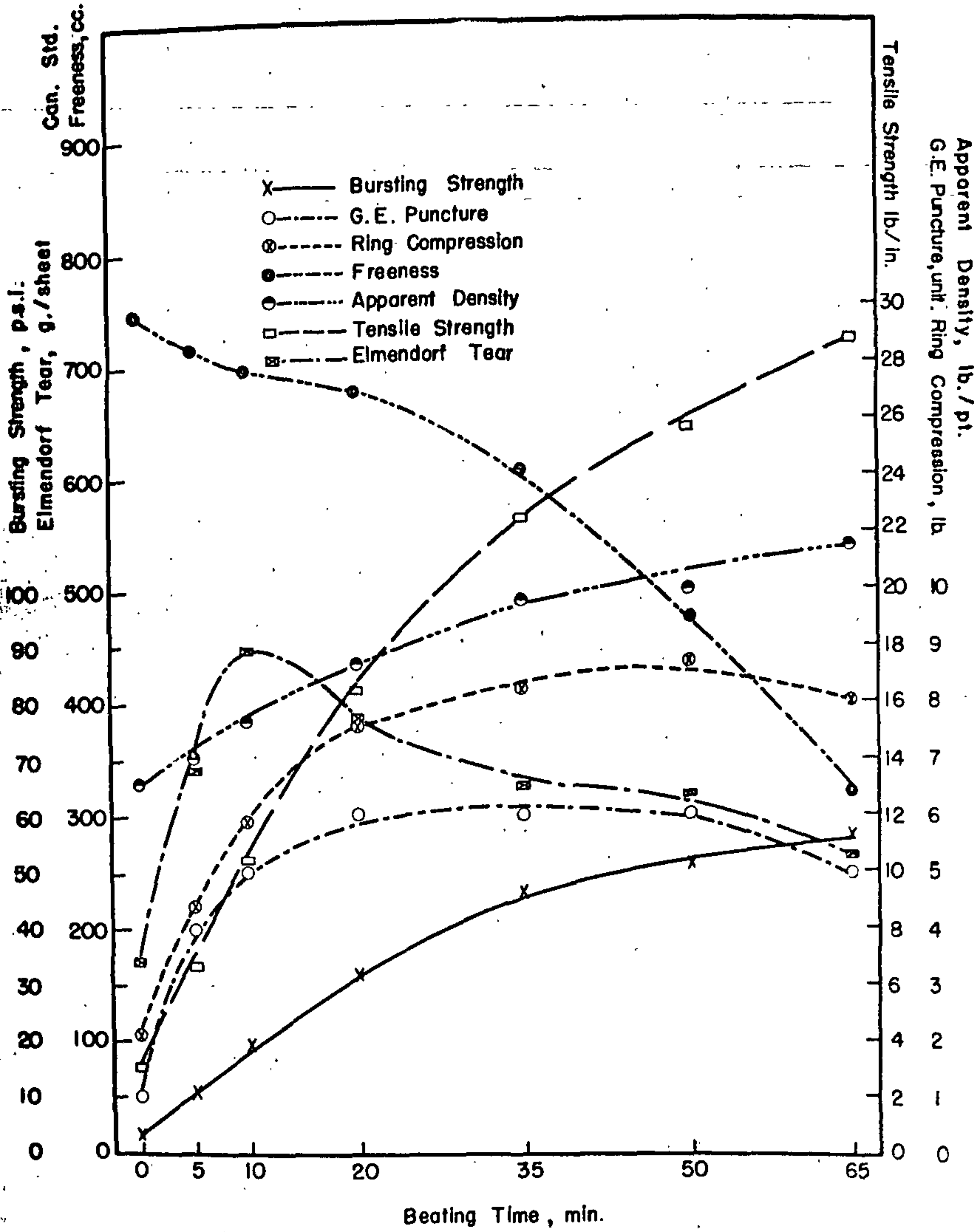


Figure 2. Strength Development, 1-1/2-lb. Valley Beater

G. E. puncture, Elmendorf tear, Canadian standard freeness, ring compression, tensile strength, and stretch. It may be noted that the G. E. puncture values increased rapidly during the early minutes of beating, then leveled off and decreased during the final minutes. Inasmuch as the relationship of the G. E. puncture test and other conventional tests is the objective of this work, some comparisons should be made. Of the various tests, the beating curve for Elmendorf tear most resembles that for G. E. puncture. From this observation, it may be concluded that a high percentage of long fibers are a prerequisite for high G. E. puncture strength inasmuch as this is a normal requirement for high tearing strength. This is substantiated by observing the Bauer-McNett fiber classification results in Table II where it may be noted that high percentages of long fibers and high G. E. puncture results occur at approximately the same beating intervals. This holds true with the exception of zero beating time which of course is associated with the highest percentage of long fibers, and the discrepancy may be explained in part by poor formation and bonding before the fiber bundles are brushed out. It may be seen in Figure 2 that ring compression also increases rapidly during the early part of the beating cycle and resembles to some extent the behavior of G. E. Puncture. The remaining physical tests--bursting strength, apparent density, tensile, and stretch---all increase more gradually as beating time increases.

The test results obtained in connection with the beater evaluation made using the Abbé pebble mill are given in Table III and presented graphically in Figure 3. The Bauer-McNett fiber classification results

TABLE II

BAUER-McNETT FIBER CLASSIFICATION FOR VALLEY BEATER INTERVALS

Fiber Retained, %
Beating Intervals, min.

Screen size	0	5	10	20	35	50	65
On 20 mesh	87.9	85.2	84.8	85.1	82.4	78.0	70.6
Through 20 on 35 mesh	7.9	8.7	8.0	5.8	4.2	4.3	5.2
Through 35 on 65 mesh	3.7	5.1	5.2	5.4	5.6	6.2	6.3
Through 65 on 100 mesh	0.5	0.9	0.8	0.8	0.9	1.4	1.4
Through 100 mesh	--	--	1.2	2.9	6.9	10.1	16.5

TABLE III

THE EFFECT OF THE TYPE AND DEGREE OF BEATING ON SHEET PROPERTIES

Abbé Pebble Mill

Beating Time, min.	Freeness, cc. (Canadian Standard)	Basis Weight, lb. 25x40/500	Caliper points	Apparent Density	Bursting Strength, p.s.i.	Bursting Strength, Factor[a]	G. E. Puncture, units	G. E. Puncture, Factor[a]	Tensile Strength, lb./in.	Tensile Strength, Factor[a]	Stretch, %	Ring Compression, lb.	Ring Compression, Factor[a]	Elmendorf Tear, g./sheet	Elmendorf Tear, Factor[a]
0	705	40.2	5.6	7.2	13.0	0.323	4	0.100	6.6	0.164	1.8	4.7	0.117	66	1.64
20	690	38.6	5.1	7.6	19.6	0.508	6	0.155	9.0	0.233	2.2	6.1	0.158	79	2.05
40	675	39.3	5.0	7.9	27.1	0.690	6	0.153	11.8	0.300	2.8	6.8	0.173	86	2.19
60	670	39.4	5.0	7.9	27.8	0.706	7	0.178	11.7	0.297	3.0	6.5	0.165	82	0.08
100	620	38.9	4.2	9.3	40.4	1.039	6	0.154	16.2	0.416	3.9	6.5	0.167	72	1.85
160	515	39.2	3.8	10.3	47.0	1.199	6	0.153	19.9	0.508	4.7	6.9	0.176	65	1.66
270	255	39.5	3.7	10.7	54.3	1.375	5	0.127	22.9	0.580	5.2	6.8	0.172	51	1.29

Beating Conditions: Type of refiner, Abbé Pebble mill; Furnish, unbleached kraft; Consistency: 3%; Temperature, 68°F.

[a] Factors were calculated by dividing test result by the basis weight.

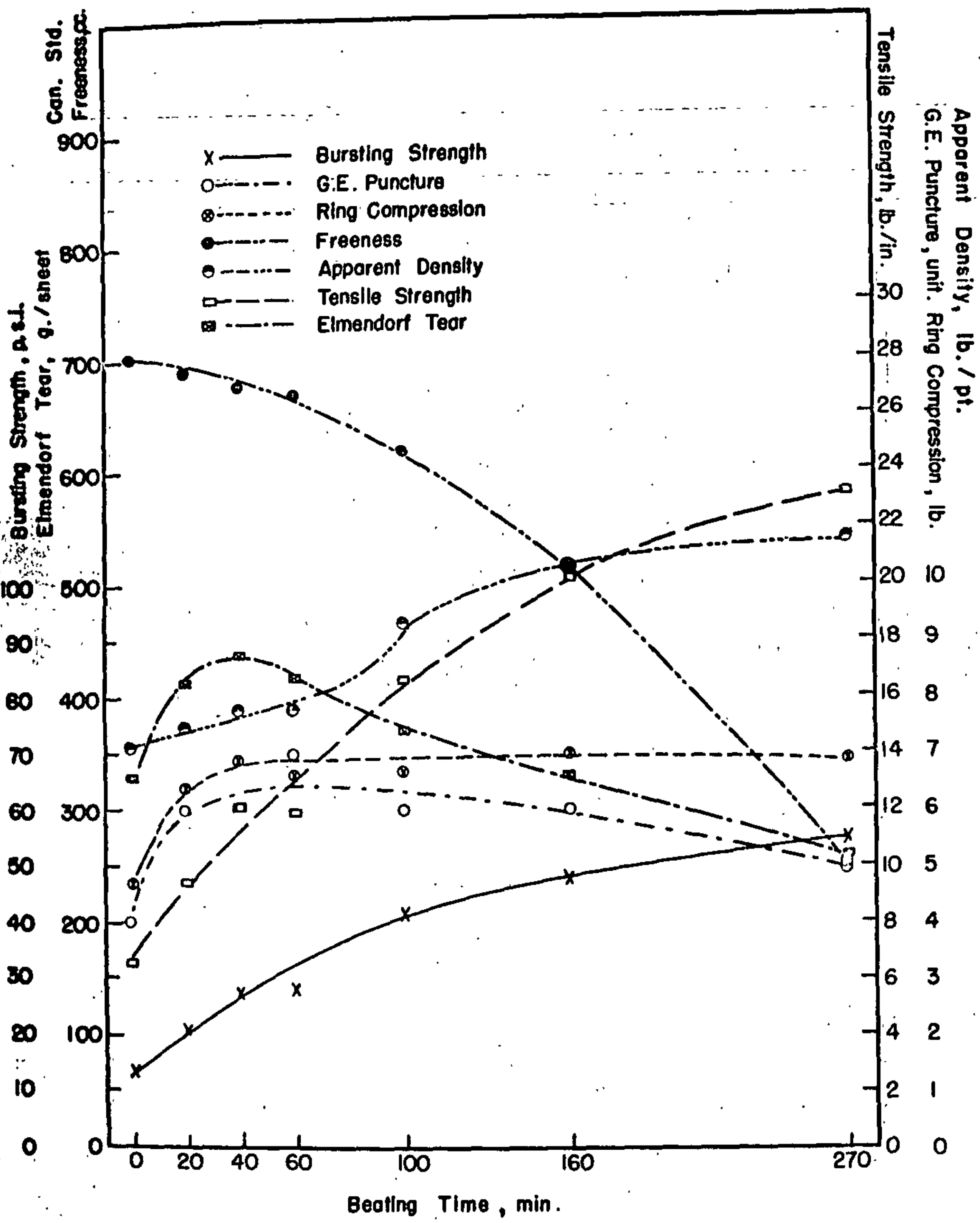


Figure 3. Strength Development (Abbé Pebble Mill)

are shown in Table IV. It may be noted from the data presented in these figures and tables that, as in the case of the Valley beater evaluation, the G. E. puncture data shows the same trends as Elmendorf tear. Ring compression strength rises quickly to a maximum in the period of initial beating but does not show the gradual decline that is exhibited by both tear and G. E. puncture as beating time increases. Again it appears that a well-formed, long-fibered sheet will produce the highest G. E. puncture and Elmendorf tear results. The bursting strength, tensile strength, stretch, and apparent density curves follow the characteristic pattern of a gradual increase as beating progressed--behavior which is very much different from that associated with G. E. puncture. The G. E. puncture follows more closely the characteristic pattern of the Elmendorf tear.

The test results obtained in connection with the beater evaluation made using the Jokro mill are given in Table V and presented graphically in Figure 4. The Bauer-McNett fiber classification results are shown in Table VI. In general, the curves obtained by means of the Jokro mill parallel the results obtained by the Valley beater and Abbé pebble mill, and once again a similarity between the Elmendorf tear and G. E. puncture curves is noted and is unique in that the G. E. puncture test does not show a similar parallelism for any of the other tests, all of which exhibited gradually increasing values as beating time increased.

In order to compare the action of each of the three beaters on individual test characteristics, several graphs have been prepared, one of which shown in Figure 5 illustrates the relationship between

TABLE IV

BAUER-McNETT FIBER CLASSIFICATION FOR PEBBLE MILL BEATING INTERVALS

Fiber Retained, %
Beating Intervals, min.

Screen size	0	20	40	60	100	160	270
On 20 mesh	77.0	78.5	81.1	76.6	75.8	77.0	72.3
Through 20 on 35 mesh	9.2	7.8	6.2	5.6	5.0	5.1	5.8
Through 35 on 65 mesh	5.6	5.5	6.3	6.1	6.0	5.6	6.0
Through 65 on 100 mesh	1.4	1.1	0.8	0.8	0.8	1.0	1.0
Through 100 mesh	6.8	7.1	5.6	10.9	12.4	11.3	14.9

TABLE V

THE EFFECT OF THE TYPE AND DEGREE OF BEATING ON SHEET PROPERTIES

Jokro Mill

Beating Time, min.	Freeness, cc. (Canadian Standard)	Basis Weight, lb. 25x40/500	Caliper points	Apparent Density	Bursting Strength, p.s.i.	Bursting Strength, Factor[a]	G. E. Puncture, units	G. E. Puncture, Factor[a]	Tensile Strength, lb./in.	Tensile Strength, Factor[a]	Stretch, %	Ring Compression, lb.	Ring Compression, Factor[a]	Elmendorf Tear, g./sheet	Elmendorf Tear, Factor[a]
10	715	40.0	5.0	8.0	23.1	0.578	6	0.150	11.4	0.285	2.2	6.5	0.162	97	2.42
20	700	40.1	4.5	8.9	31.0	0.773	7	0.175	15.2	0.379	2.6	6.8	0.170	86	2.14
30	660	39.5	4.1	9.6	39.8	1.008	7	0.177	16.9	0.428	2.7	7.0	0.177	73	1.85
45	605	39.2	4.0	9.8	44.4	1.133	7	0.179	20.0	0.510	3.2	8.0	0.204	66	1.68
60	525	40.0	4.0	10.0	49.0	1.225	6	0.150	22.7	0.568	3.5	7.6	0.190	67	1.68
80	370	39.1	3.6	10.9	50.7	1.297	6	0.153	24.0	0.614	3.6	7.6	0.194	56	1.43

Beating Conditions: Type of refiner, Jokro Mill, Furnish, Unbleached kraft; Consistency, 6%, Temperature, 77°F.

[a] Factors were calculated by dividing test result by the basis weight.

TABLE VI

BAUER-McNETT FIBER CLASSIFICATIONS FOR JOKRO MILL BEATING INTERVALS

Fiber Retained, %
Beating Intervals, min.

Screen size	10	20	30	45	60	80
On 20 mesh	75.4	75.2	74.7	76.4	77.6	73.6
Through 20 on 35 mesh	9.2	10.0	9.2	8.1	4.7	4.2
Through 35 on 65 mesh	6.4	5.8	6.0	6.1	6.4	7.6
Through 65 on 100 mesh	1.2	1.2	1.2	1.1	1.4	1.9
Through 100 mesh	7.8	7.8	8.9	8.3	9.9	12.7

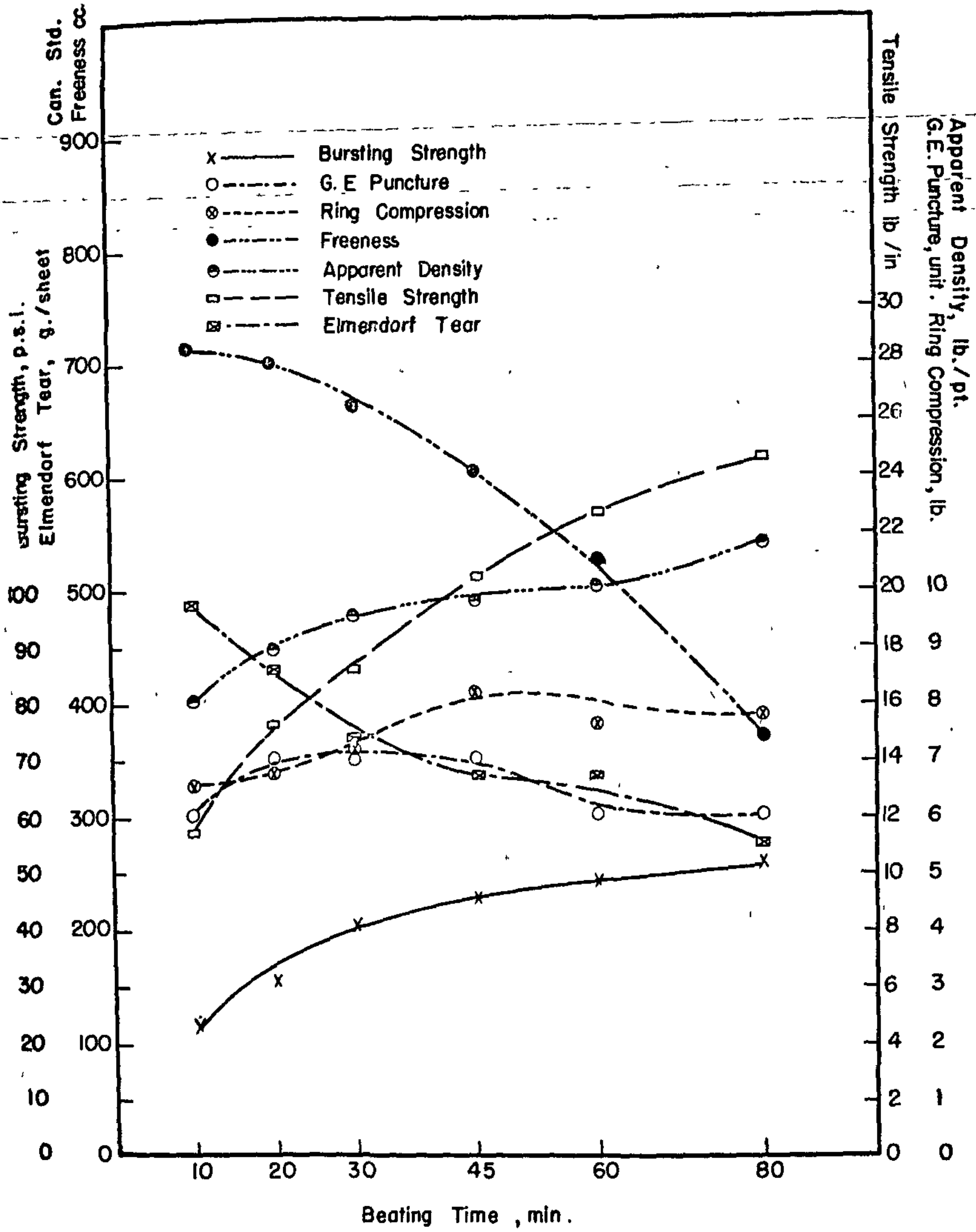


Figure 4. Strength Development, Jokro Mill

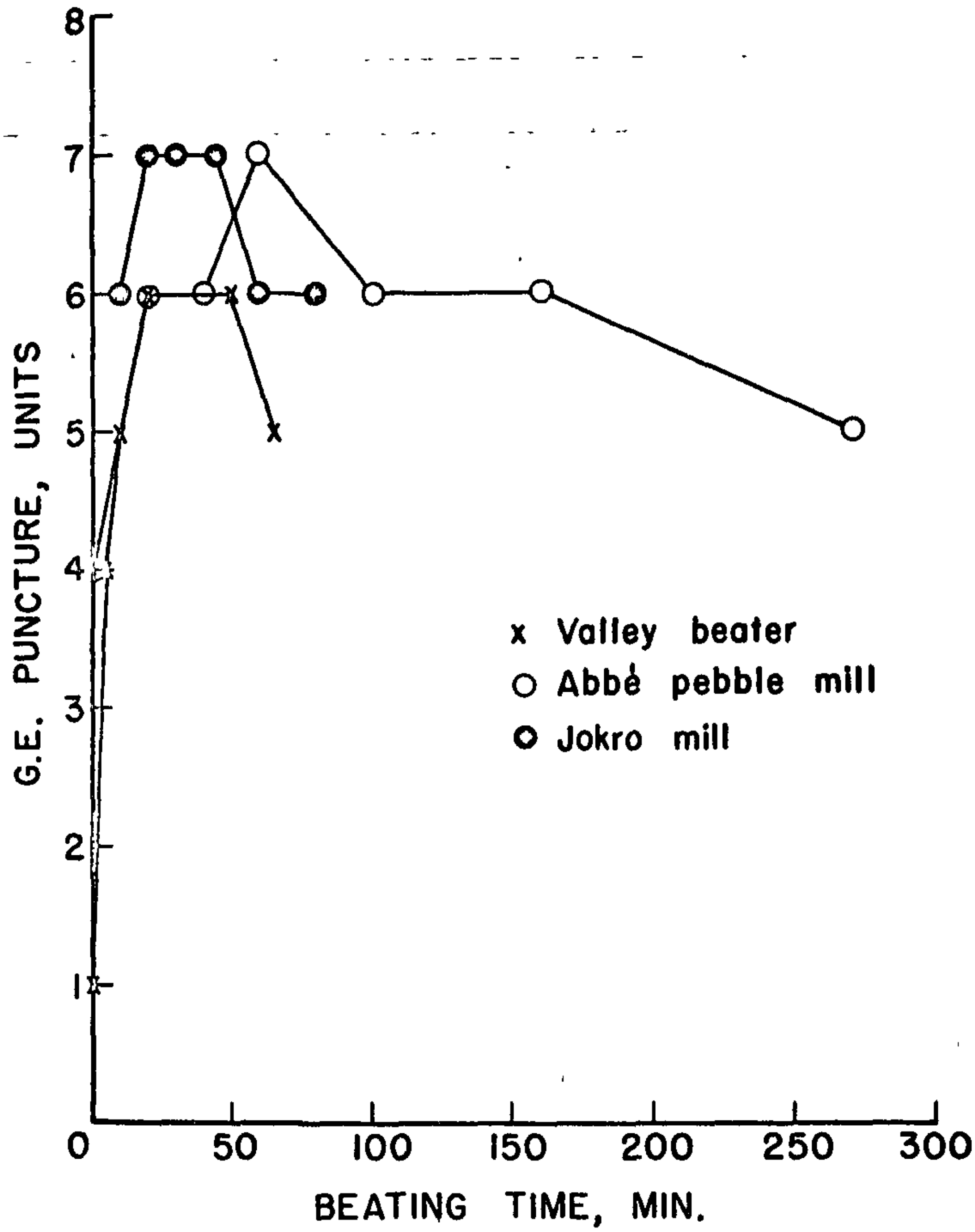


Figure 5

Comparison of G. E. Puncture Strength Development versus Beating Time for the Valley Beater, Abbé Pebble Mill, and Jokro Mill beating time and the G. E. puncture test on stock refined in the Valley beater, Abbé pebble mill, and Jokro mill. Figure 5 shows that the highest G. E. puncture results were obtained using the Jokro mill or the Abbé pebble mill. The results for the Valley beater decreased after the shortest elapsed beating time, whereas the results for the Abbé pebble mill decreased more slowly as did the results for the Jokro mill which appeared to decrease at an intermediate rate. Figure 6 shows the relationship between beating time and bursting strength for each of the three beaters. There is a similarity in the relationship for the Valley beater and the Jokro mill; both show a very rapid increase in bursting strength. However, the relationship for the Abbé pebble mill is quite different, the increase in bursting strength being considerably more gradual. Figure 7 shows the relationship between beating time and tensile strength for the three beaters. The relationships parallel very closely those for bursting strength which were just discussed. Tensile strength increases rapidly for the Valley beater and Jokro mill but more slowly for the Abbé pebble mill. In Figure 8 the relationships between beating time and Elmendorf tear are presented for the Valley beater, Jokro mill, and Abbé pebble mill. Once again the action of the Valley beater parallels the action of the Jokro mill whereas the action of the Abbé pebble mill is different. The stock processed in the Valley beater and that processed in the Jokro mill exhibit a sharp increase in tearing strength during the early minutes of beating and then a relatively sharp decrease as beating continues. Stock processed in the Abbé pebble mill, however, shows both a more gradual increase during

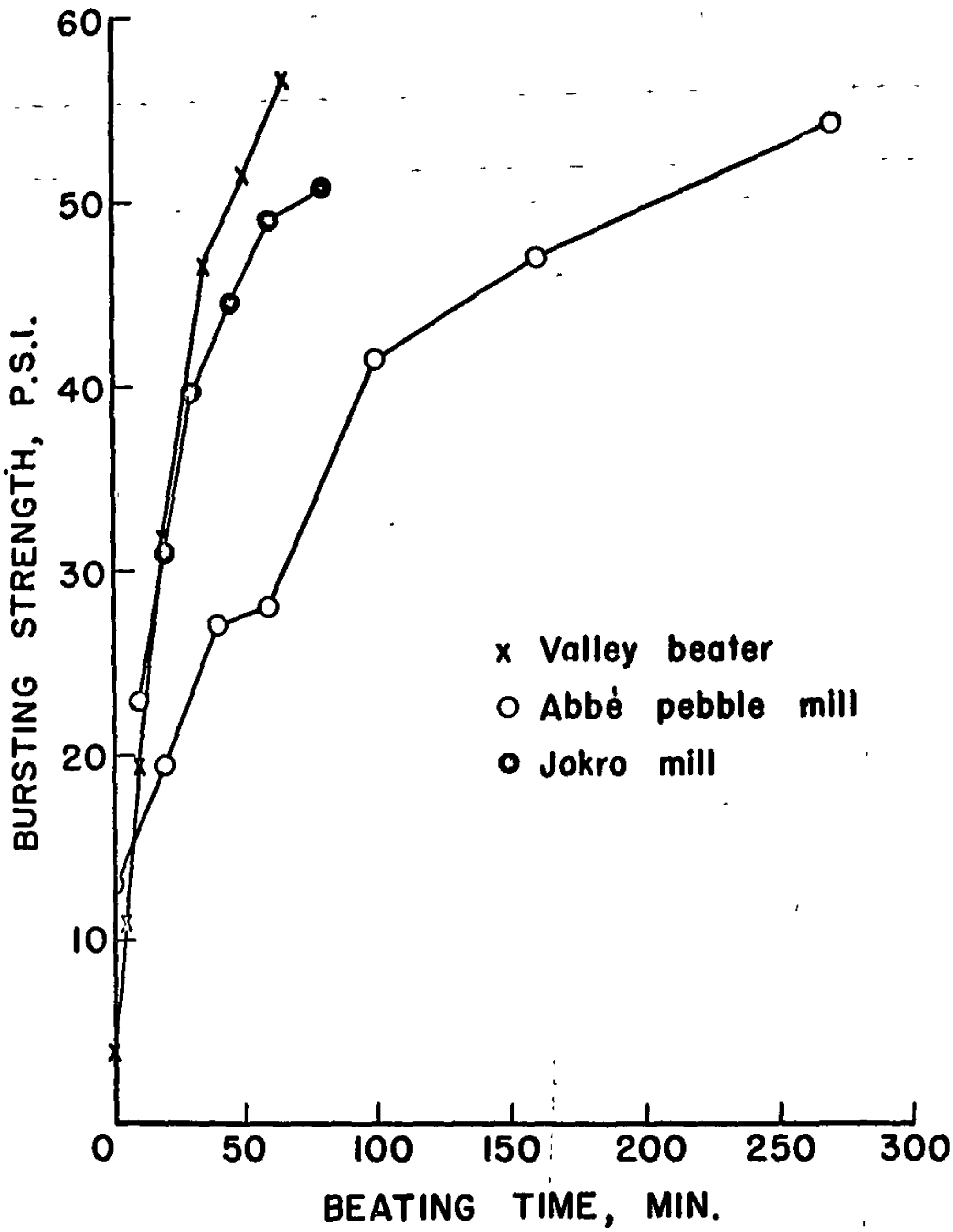


Figure 6

Comparison of Bursting Strength Development _versus_ Beating Time for the Valley Beater, Abbé Pebble Mill and Jokro Mill

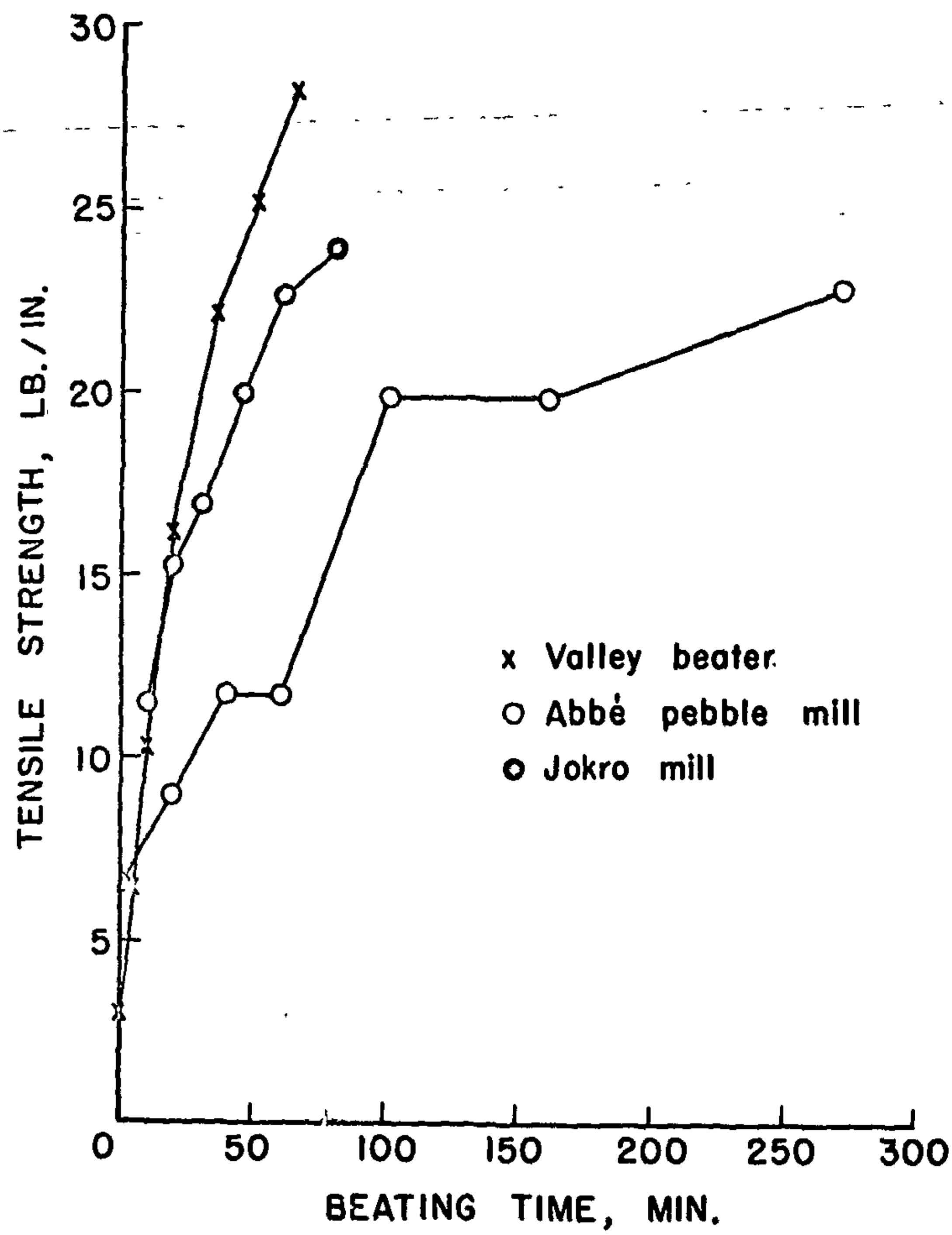


Figure 7

Comparison of Tensile Strength Development versus Beating Time for the Valley Beater, Abbé Pebble Mill, and Jokro Mill

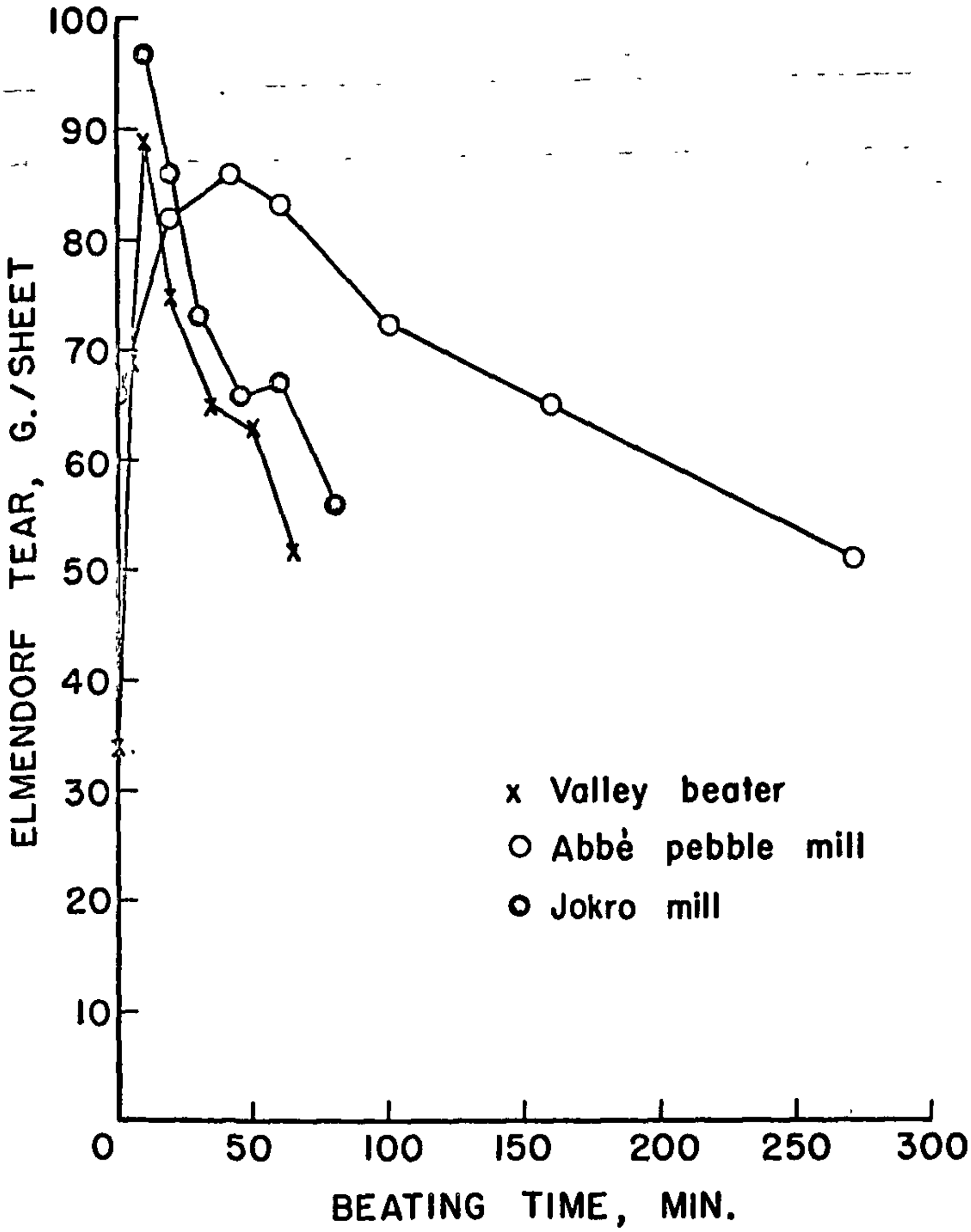


Figure 8

Comparison of Elmendorf Tear Development versus Beating Time for the Valley Beater, Abbé Pebble Mill, and Jokro Mill the early minutes as well as a more gradual decrease during the later minutes of beating.

These side by side comparisons show the similarity of beating action for the Valley beater and the Jokro mill, both of which appear to reduce fiber length rapidly whereas the action of the pebble mill is much slower.

In summation on the effects of the type and degree of beating, it may be concluded that of the physical tests studied, only Elmendorf tear behavior shows a marked similarity to the behavior of G. E. puncture when plotted against beating time. Both G. E. puncture and Elmendorf tear reach a maximum value early in the beating cycle and then decrease gradually as beating continues, whereas the other tests--bursting strength, ring compression, tensile strength, stretch, and apparent density--increase gradually throughout the entire beating period.

EFFECT OF WEIGHT ON G. E. PUNCTURE

In order to study the effect of weight on the G. E. puncture test, handsheets of various weights were made from pulp beaten in a Valley beater in one series of tests to a Canadian standard freeness of 600 cc. and, in a second series, to a Canadian standard freeness of 400 cc. The basis weights on a scale of pounds (25 x 40--500) were 42, 67, 92, 125, and 150 for both series. The test results obtained on these sheets are given in Table VII and presented graphically in Figures 9, 10, 11, and 12.

TABLE VII

EFFECT OF SHEET PROPERTIES OF VARYING WEIGHT AT A GIVEN FREENESS LEVEL

Basis Weight, lb. 25x40—500	Caliper, points	Apparent Density	Bursting p.s.i.	Strength, Factor[a]	G. E. units	Puncture, Factor[a]	Tensile, lb./in.	Tensile, Factor[a]	Stretch, %	Ring lb.	Compression, Factor[a]	Elmendorf g./sheet	Tear, Factor[a]
Part I: (400 cc. Can. Std.—Pressed at 50 p.s.i.)													
38.8	4.0	9.7	50.9	1.31	5	0.129	24.4	0.629	3.3	8.4	0.216	55	1.42
61.9	5.4	11.5	84.6	1.37	10	0.162	40.0	0.646	3.3	24.7	0.399	107	1.73
85.4	7.0	12.2	122	1.43	15	0.176	56.2	0.658	3.6	43.3	0.507	161	1.89
117.6	9.3	12.6	148	1.26	22	0.187	71.4	0.607	3.9	73.3	0.623	262	2.23
140.9	10.9	12.9	181	1.28	29	0.206	87.6	0.622	4.2	103.9	0.737	309	2.19
Part II: (600 cc. Can. Std.—Pressed at 50 p.s.i.)													
39.0	4.2	9.3	39.1	1.00	7	0.179	18.7	0.479	3.0	6.9	0.177	65	1.67
62.5	6.1	10.2	68.4	1.09	12	0.192	31.6	0.506	3.2	22.6	0.362	119	1.90
84.7	8.1	10.5	91.0	1.07	19	0.224	41.4	0.489	3.2	37.8	0.446	189	2.23
117.0	10.4	11.2	115.0	0.98	27	0.231	55.6	0.475	3.2	66.1	0.565	290	2.48
145.0	12.6	11.5	145.0	1.00	35	0.241	68.6	0.473	3.2	82.1	0.566	350	2.41

[a] Factors were calculated by dividing test results by the basis weight.

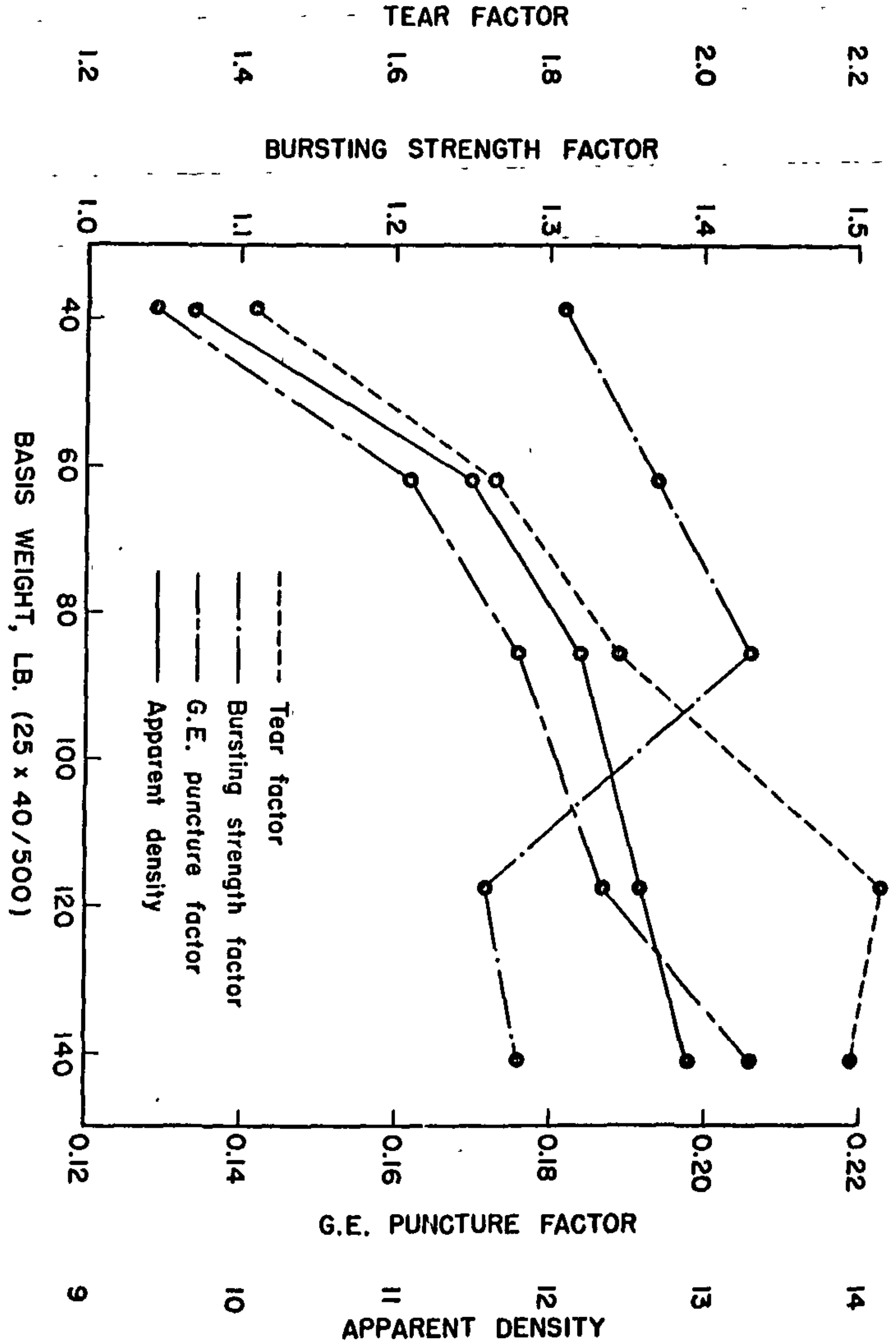


Figure 9

Effect on Sheet Properties of Varying Weight at a Given Freeness Level (600 cc. Can. Std.)

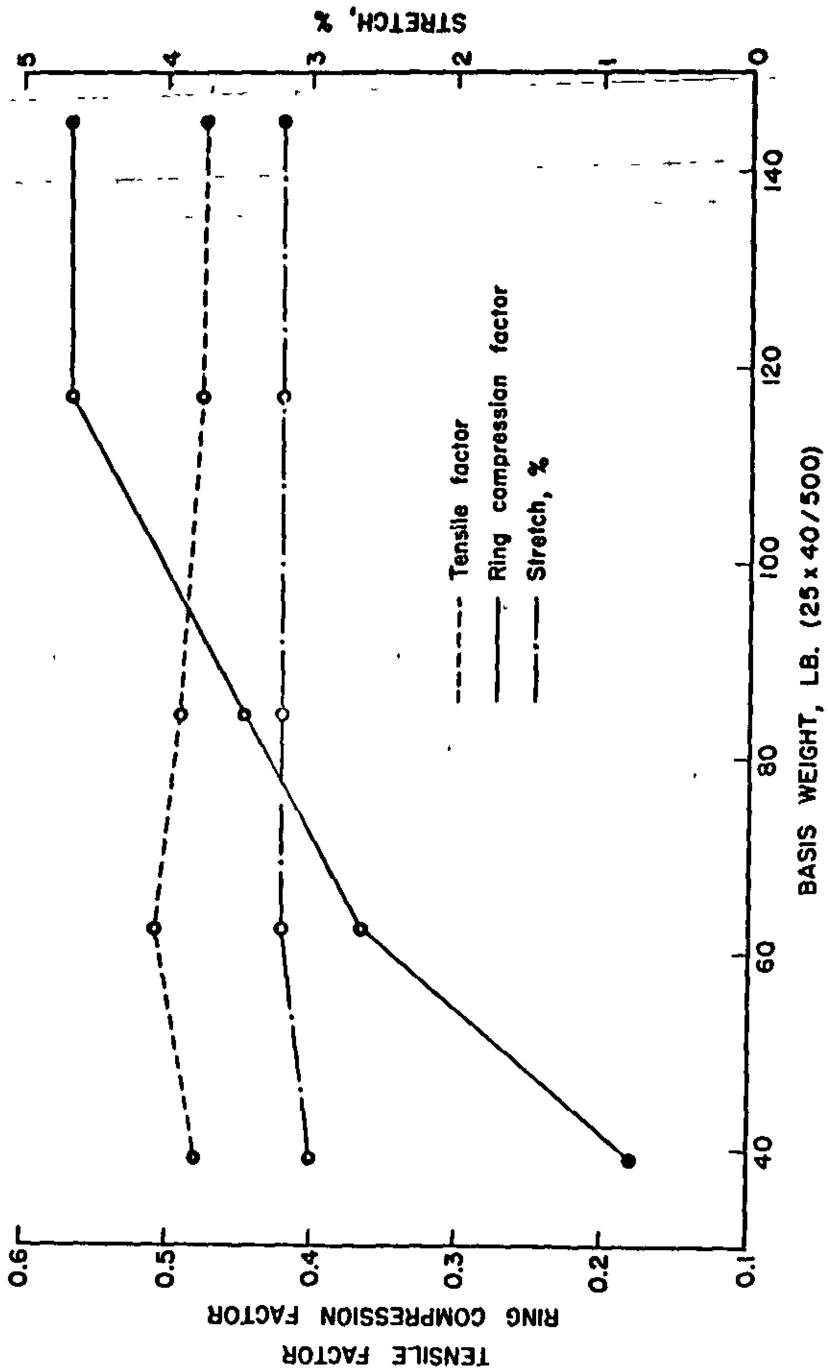
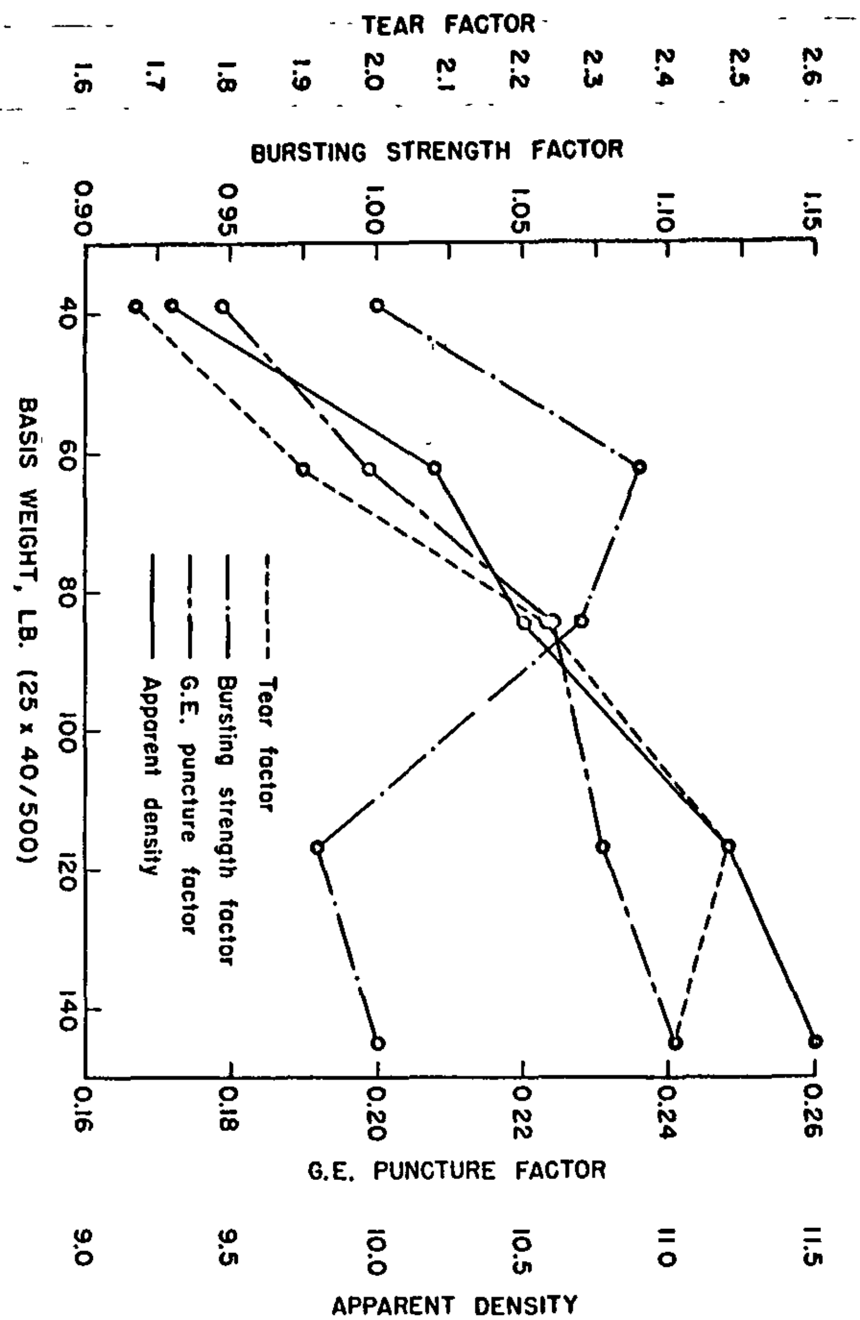


Figure 10

Effect on Sheet Properties of Varying Weight at a Given Freeness Level (600 cc. Can. Std.)



Effect on Sheet Properties of Varying Weight at a Given Freeness Level (400 cc. Can. Std.)

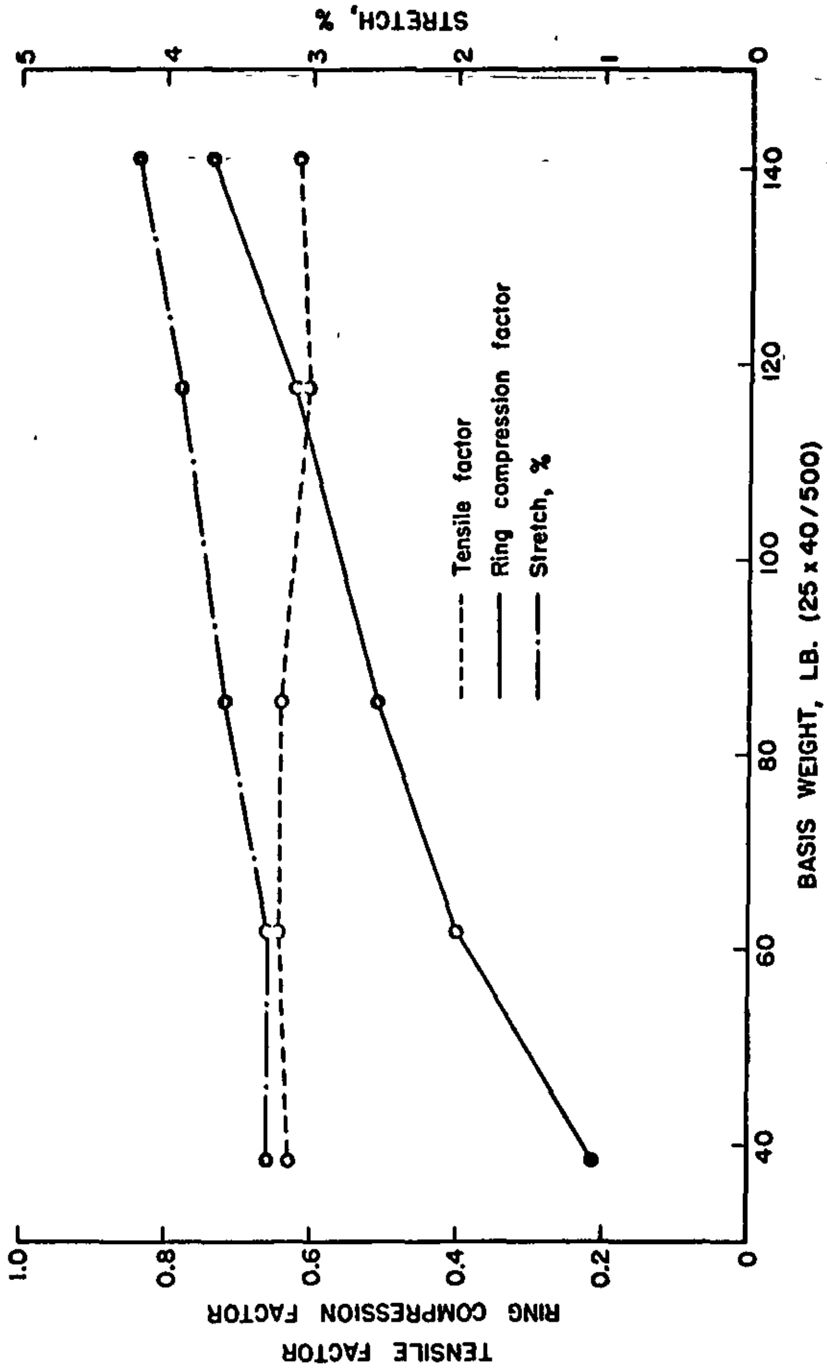


Figure 12

Effect on Sheet Properties of Varying Weight at a Given Freeness Level (400 cc. Can. Std.)

It may be noted from the test results shown in Table VII that the magnitude of all tests increased as weight increased. This observation is in keeping with known behavior. However, in some cases, the increase is small for a given weight increase whereas in other cases the increase is large. In order to compare the rate of change taking place, the results have been calculated on a unit weight basis. These values (factors) are shown in Table VII and Figures 9, 10, 11, and 12. Figures 9 and 10 show the various strength factors in graphic form for the handsheets made from pulp beaten to a Canadian standard freeness level of 600 cc. It may be noted that the tear factor, G. E. puncture factor, ring compression factor, and apparent density all increased. The bursting strength factor increased up to a basis weight level of approximately 60 lb. (25 x 40/500) and then decreased at the higher weight levels. The tensile factor and percentage stretch remained relatively constant over the entire range of basis weight. Figures 11 and 12 present graphically the various strength factors for the handsheets made from pulp beaten to a Canadian standard freeness level of 400 cc. As noted previously for the results obtained at a freeness level of 600 cc. Canadian standard, the factors for G. E. puncture, Elmendorf tear, apparent density, and ring compression increased whereas the bursting strength factor increased up to a basis weight level of approximately 80 lb. (25 x 40/500), and then decreased as weight continued to increase. The tensile factor remained relatively constant and percentage stretch increased slightly.

Of special interest is the relationship of the G. E. puncture test to the other strength measurements employed in this study. A further inspection of the data in Table VII and the graphic presentations of Figures 9 through 12 indicates that there appears to be a marked similarity in the behavior of the Elmendorf tear results and the G. E. puncture results. On the basis of this similarity, semilogarithmic plots were prepared and are shown in Figure 13 for the handsheets prepared from pulp beaten to a Canadian standard freeness level of 600 cc. and in Figure 14 for the handsheets prepared from pulp beaten to a Canadian standard freeness level of 400 cc. It may be seen from an inspection of these graphs that both Elmendorf tear and G. E. puncture conform rather well to a linear configuration when basis weight is plotted logarithmically as the dependent variable $\underline{y}$ and either the G. E. puncture or Elmendorf tear factor is plotted on a linear scale as the independent variable $\underline{x}$.

In summation, it may be concluded that the behavior of the G. E. puncture test paralleled that of the Elmendorf tear test very closely. Both tests exhibited more strength units per pound of fiber at higher weights than at lower weights. The ring compression factor also behaved similarly. In contrast to this behavior, bursting strength exhibited increasing strength per pound of fiber only up to a given weight level beyond which it exhibited decreasing strength per pound of fiber. Percentage stretch and the tensile factor remained appreciably unchanged over the range of basis weight that was used for this investigation.

EFFECT OF DENSITY ON G. E. PUNCTURE

Sheet density was varied by wet pressing at pressures of 25, 50, and 100 p.s.i. The test results are shown in Table VIII. It may

TABLE VIII

EFFECT ON SHEET PRPPERTIES OF VARYING DENSITY BY WET PRESSING AT VARIOUS PRESSURES

Canadian Standard Freeness 590 cc.

Wet Pressing Pressure, p.s.i.	Basis Weight, lb. 25x40/500	Caliper, points	Apparent Density	Bursting p.s.i.	Strength, Factor[a]	G. E. units	Puncture, Factor[a]	Tensile, lb./in.	Tensile, Factor[a]	Stretch, %	Ring lb.	Compression, Factor[a]	Elmendorf g./sheet	Tear Factor[a]
25	39.4	4.2	9.4	38.6	0.980	7	0.178	19.3	0.490	2.8	6.6	0.168	68	1.73
50	40.0	4.4	9.1	39.3	0.982	7	0.175	19.5	0.488	2.8	8.6	0.215	70	1.75
100	39.4	4.1	9.6	42.6	1.081	7	0.178	19.2	0.487	3.1	8.6	0.218	64	1.62

[a] Factors were calculated by dividing test result by the basis weight.

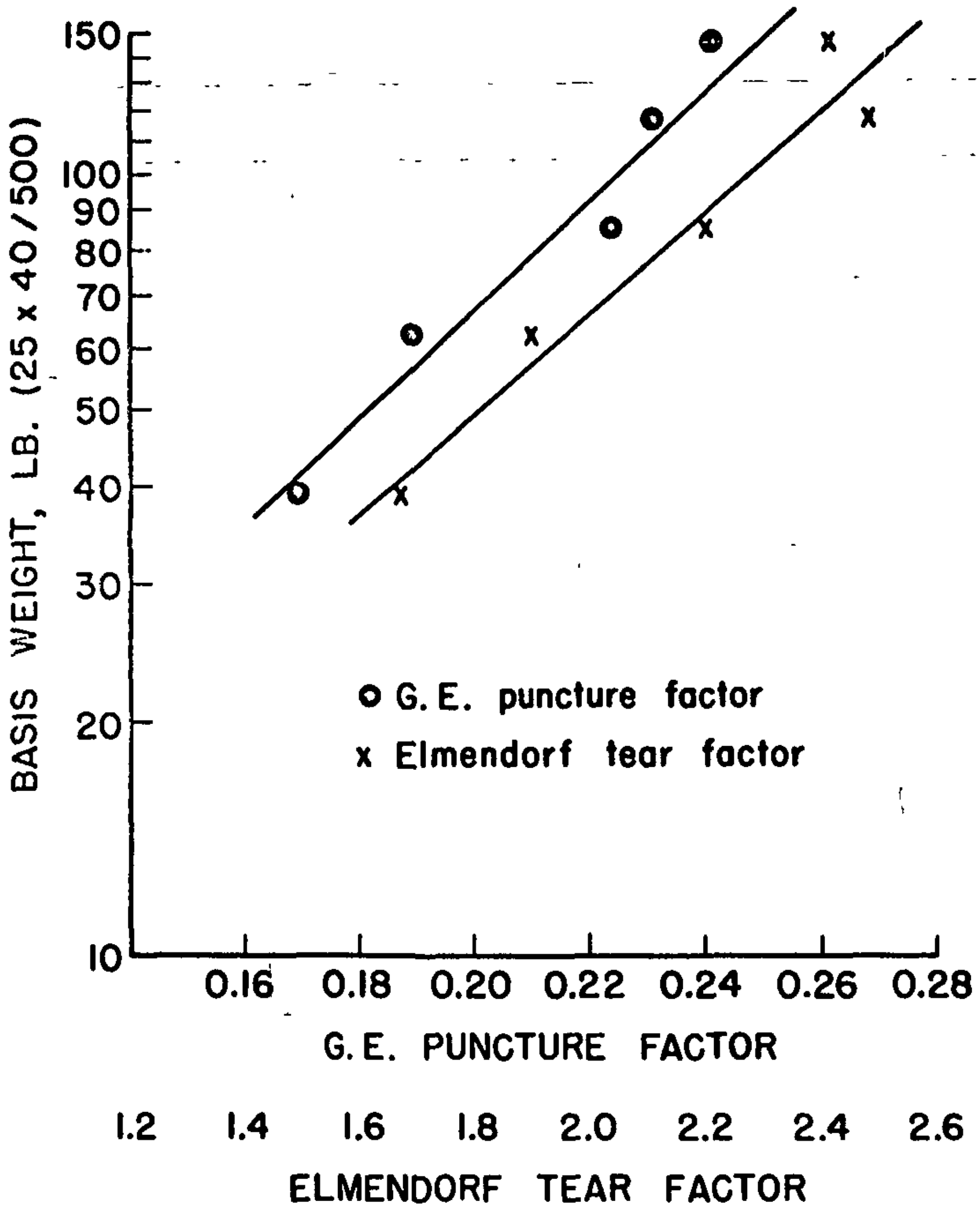


Figure 13

Relationship of the G. E. Puncture Factor and Elmendorf Tear Factor to Basis Weight (600 cc. Can. Std. Freeness)

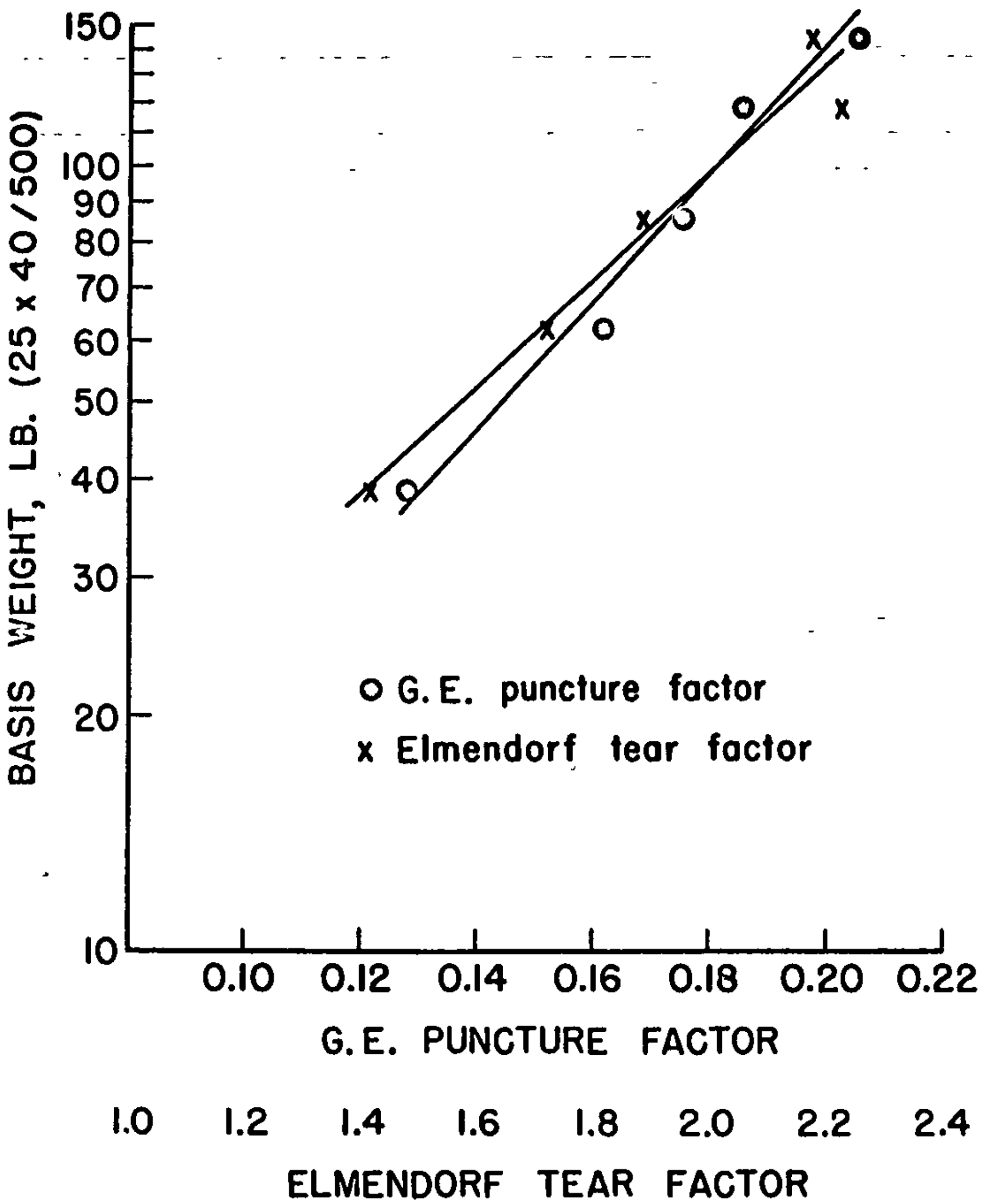


Figure 14

Relationship of the G. E. Puncture Factor and Elmendorf Tear Factor to Basis Weight
(400 cc. Can. Std. Freeness)

be noted that apparent density was not affected very greatly by this range of pressures. However, several comparisons of interest may be made on the results for the sheet prepared with the minimum and maximum pressures. It may be seen that the bursting strength was 0.980 at 25 p.s.i. and 1.081 at 100 p.s.i. indicating that wet pressing at 100 p.s.i. increased bursting strength. G. E. puncture factors were 0.178 at both 25 and 100 p.s.i. indicating that this range of pressures had no effect on G. E. puncture strength. The tensile and stretch factors were only slightly affected. However, the ring compression factor increased from 0.168 at the lowest pressure to 0.218 at the highest pressure. The tear factor decreased from 1.73 to 1.62. The effects noted are in keeping with known principles--e.g., increasing density by means of wet pressing increases bursting strength and decreases tearing strength.

EFFECT OF NONFIBROUS ADDITIVES ON G.E. PUNCTURE

The procedures used in preparing sheets from pulp in which three types of additives were blended have been discussed previously. It may be recalled that the following additives were studied: Hyamine in amounts of 0.5 and 5.0% and Lycoid in amounts of 0.25 and 1.0%. The test results obtained on the sheets thus prepared are given in Table IX. In the case of Hyamine-treated sheets, it may be noted that 5.0% Hyamine treatment resulted in a sheet with lower bursting strength, tensile strength, stretch, and ring compression test results, whereas the G. E. puncture and Elmendorf tear results were relatively unaffected by the Hyamine. As indicated previously, Hyamine tends to reduce fiber bonding and in so doing promotes the formation of a rather

TABLE IX

EFFECT OF 10 FIBROUS ADDITIVES ON SHEET PROPERTIES

Basis Weight, lb. 25 x 40--500	Caliper, points	Apparent Density	Bursting p.s.i.	Strength, Factor[a]	G. E. units	Puncture, Factor[a]	Tensile, lb./in.	Tensile, Factor[a]	Stretch, %	Ring Compression, lb.	Ring Compression, Factor[a]	Elmendorf g./sheet	Tear, Factor[a]
						0.5% Hyamine							
41.9	4.5	9.3	34.8	0.831	8	0.191	16.1	0.384	2.6	9.1	0.217	78	1.86
						5.0% Hyamine							
40.4	4.7	8.6	22.6	0.559	7	0.173	12.3	0.304	2.0	6.7	0.165	79	1.96
						0.25% Lycoid							
39.6	4.3	9.2	39.0	0.965	7	0.177	19.4	0.490	3.0	8.2	0.207	71	1.79
						1.0% Lycoid							
39.1	4.2	9.3	46.3	1.184	7	0.179	19.4	0.496	3.0	7.6	0.194	62	1.59
						1.0% Starch							
41.7	4.5	9.3	33.7	0.808	8	0.192	18.3	0.439	2.5	8.7	0.209	77	1.85
						2.0% Starch							
39.3	4.3	9.3	31.[illegible]	0.799	7	0.176	16.6	0.417	2.6	7.3	0.183	73	1.83

[a] Factors were calculated by dividing test result by the basis weight.

loose sheet. Thus, it would be anticipated that bursting strength, tensile-strength, stretch, and ring compression would be reduced whereas the effect on G. E. puncture and Elmendorf tear would not be so evident.

The test results on handsheets prepared from pulp containing 0.25% and 1.0% Lycoid are also shown in Table IX. Since the effect of the Lycoid is to promote greater fiber bonding, it would be expected that bursting strength would increase and that tests such as tensile, stretch, and ring compression might also increase. It may be noted in Table IX that bursting strength did increase and that tensile and stretch were unchanged while ring compression decreased slightly. The effect of Lycoid on the G. E. puncture results was imperceptible although the Elmendorf tear results appeared to be reduced somewhat.